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III.

ON THE VEILED SOLAR SPOTS.

By L. Trouvelot.

Read by William A. Rogers, Oct. 12, 1875.

It is now pretty well established that the visible surface of the sun is a gaseous envelope called "the chromosphere;" mainly composed of incandescent hydrogen gas, with which are occasionally associated some metallic vapors usually occupying the lower strata. To all appearances, the granulations called "rice grains," the faculæ and the protuberances, are phenomena belonging to the chromosphere; in fact, they are the chromosphere itself seen under the particular forms and aspects peculiar to it. Ordinarily this envelope has a thickness of 10″ or 15″. This thickness, however, is by no means constant, varying from day to day within certain narrow limits.

At no time since I have observed the sun, have I seen the chromosphere so thin and shallow as during the present year, and especially between June 10 and August 18. I had before quite often observed local depressions and upheavals of the chromosphere, sometimes extending over large surfaces, but I had never before observed such a general subsidence.

So thin was the chromosphere during this period, that it was sometimes very difficult to obtain its spectrum by placing the slit of the spectroscope tangent to the limb of the sun. This was especially the case on the afternoon of August 9.

This unusual thinness of the chromosphere could be easily recognized without the assistance of the spectroscope. Indeed, the phenomenon was even more interesting seen through the telescope, as, with it, the structure of the photosphere, lying as it does under the envelope of the chromosphere, could be better seen through the thin veil formed by the greatly attenuated chromospheric gases.

That the gases forming the chromosphere are sometimes thin enough to become transparent is a phenomenon which I have observed hundreds of times; as is abundantly proved by the numerous drawings of protuberances which I have made at the Harvard College Observatory, in which the limb of the sun is seen through the base of the protuberances in front of it. In plate X, figure 3, there occurs a very striking instance, where two small prominences are seen through a larger protuberance nearer the observer.

During this period of general subsidence, the granulations appeared to be smaller and farther apart than usual, and consequently the light-gray colored background upon which they are seen projected was more distinct, as it occupied more space than formerly. During this period, the light-giving element would appear to have been less than usual.

I am not aware that the phenomena of which I shall speak in this communication have been before observed; but I cannot speak positively on this point, owing perhaps to the somewhat confused nomenclature of solar physics.

Ever since I have observed the sun with instruments of a large aperture, I have noticed that the light-gray colored background seen between the granulations is by no means uniform, as it is generally stated to be. On the contrary, it is greatly and strikingly diversified. Aside from the very small black dots called "pores," patches of a darker gray are irregularly distributed all over the surface of the sun. But partly owing to the effect of perspective, and partly on account of the thicker strata of the chromospheric gases through which they are necessarily seen near the limb, they disappear gradually as they approach the border.

These dark spots have been so remarkable during the present year, and so conspicuous during the period of the greatest subsidence of the chromosphere, that I have availed myself of every favorable opportunity to study them. So strongly were they marked, that when one had passed the field of view, it could be easily found again among many others, even after the lapse of several hours. Of the most striking and complicated, I have made sketches.

In order to be able to count how many of these gray spots could be seen in different heliographic latitudes, and also to estimate their area with respect to the whole surface of the sun, Mr. W. A. Rogers, Assistant at the Harvard College Observatory, kindly ruled for me on glass a reticule of small squares. Though the problem is apparently a simple one, it nevertheless presented many difficulties; partly owing to the minuteness and delicacy of these objects, partly on account of the unsteadiness of the atmosphere, and partly to the many defects caused by the great amount of heat concentrated at the focus of the objective. However, the observations show clearly that, though the number of gray spots varies but little in different latitudes, in general the spots become larger and more complicated as they approach the equatorial zones.

The most marked characteristic of the gray spots is their vagueness of outline. They are never sharply defined like ordinary spots, but they appear blurred and diffused like an object seen through a mist. As I shall endeavor to show presently, these objects are really seen through the chromospheric gases which are spread as a veil over them, causing this vagueness of outlines. For this reason, I propose for them the name of *Veiled Solar Spots.*

The veiled solar spots, especially in the lower latitudes, have a remarkable tendency to assemble into small groups after the manner of ordinary spots. Sometimes three or four are seen in contact, while there are comparatively large intervals where none are to be seen. I have in several instances seen the actual formation into groups of distinct veiled spots.

The granulations of the chromosphere are seen projected upon the veiled spots, just as anywhere else, but they are not there so regularly distributed; some being closely crowded together, while others are widely scattered. Small faculæ are often formed in this manner by the aggregation of several granules into one mass. Once in a while, the granulations appear as if they were under the power of a propelling force by which they arrange themselves in files, and sometimes in capricious figures which are very remarkable.

In many cases I have observed that the granulations projected upon the veiled spots have an extraordinary mobility, to be seen nowhere else, except perhaps in the immediate vicinity of ordinary spots in full activity. Often their form and position are totally changed within a few minutes, and sometimes even within a few seconds. This was especially the case June 21. At 8h. 30m. on that day, I was observing a group of veiled spots not far from the centre of the sun, when my attention was drawn to the extraordinary mobility of the granulations covering this group. In an instant they changed their form and position, some crowding together as though briskly attracting each other, while others would fly apart as if repelled by an invisible force. Under this tumultuous conflict of forces, new veiled spots would appear and disappear in an instant, faculæ would form and vanish; in fact, all was in motion and confusion on that particular part of the sun. It was evident that immense forces were in conflict under the chromosphere.

At 2h. 0m. P.M., on the same day, several small black spots had opened through the chromosphere upon the group of veiled spots observed in the morning. At 8h. 0m. on the following morning, the group of small black spots was considerably increased, having quite a large spot on the preceding side, followed by twelve or fifteen smaller ones. On June 24, this group had attained to its maximum size. It was then very large and complicated. In fact, it was the largest group of sun spots observed thus far during the present year.

On August 8, I noticed a group of veiled spots a little south of the sun's centre. The following morning at 7h. 0m., there was at the same place a small group of half a dozen black spots disposed in a crescent shape. At 2h. 0m. P.M., the black spots had vanished, but the veiled spots still remained, having retained the characteristic crescent form of the black spots and many other details observed in the morning; and, as a proof that the chromosphere covered this spot, *the granulations could be plainly seen upon the whole, indicating clearly that this spot was seen through the veil of the chromospheric gases.*

On August 24, the same phenomenon took place. Just following the principal spot of the only group then to be seen on the surface of the sun, there was a fine group of veiled spots. The following day some black spots had made their appearance upon them. On August 27, the black spots had vanished, but in their place the veiled spots seen at first still remained, and they continued to be seen there for several days.

To all appearances, the black spots which I had seen disappear under the chromospheric gases, and which continued as veiled spots, were exactly alike and undistinguishable from the many other veiled spots scattered all over the sun ; and, had I not seen the opening of the photosphere, with the black spots, I could not have had any idea of the true nature of the veiled spots.

So far, I have only spoken of veiled spots observed in the zones where the ordinary sun spots make usually their appearance ; but, as I have said, the veiled spots are scattered all over the surface of the sun.

During this period, I had many occasions to observe very remarkable and characteristic veiled spots in very high heliographic latitudes north and south. On July 15, within a few degrees of the north pole of the sun, I observed a remarkable veiled spot, unusually large and dark. Upon it were several bright slender faculæ projected in crest shape to very high altitudes. These faculæ appeared to be precisely like those observed in lower latitudes near ordinary sun spots.

Upon this veiled spot could unmistakably be seen a small black spot, not a pore; a real opening of both chromosphere and photosphere.

On August 9, I observed another remarkable veiled spot within about 10° from the north pole, and upon it could be seen three small black spots.

On August 13, at 11h. 0m., I observed a very dark veiled spot within 6° or 8° from the north pole. It had upon it a group of small faculæ, so characteristic of the spots of lower latitudes. At 4h. 30m. in the afternoon, this veiled spot was still darker, and upon it, near a facula, a pretty large black spot was visible.

On August 24, I observed a remarkable veiled spot at about 75° south latitude.

On September 6, another large group of veiled spots was seen within 10° or 15° of the north pole. At 10h. 20m., some faculæ had formed upon it, and two black spots were distinctly visible. At 5h. 0m. in the afternoon, this group was still visible.

On September 8, within a few degrees of the north pole, I observed a fine group of two veiled spots, unusually dark and large, and near one of these spots there was a pretty large and bright facula. Ten minutes later the dark veiled spots had vanished, leaving in their place some bright faculæ. One minute later the veiled spots began to reappear, but under another form, to disappear again the next moment.

A little south-west from this last group, but in the same field of view, was another group of veiled spots apparently in full activity. Upon it three or four black spots were visible for some seconds. Upon these veiled spots the granulations had an extraordinary mobility; so much so, that I expected at every moment to see a large spot make its appearance, but in less than a minute the veiled spots and the black spots had both vanished, and in their place were formed in an instant, some very bright faculæ.

To all appearances, the veiled spots seen in high latitudes differ but very little from the ordinary sun spots of the lower latitudes, except in regard to magnitude and activity. The difference seems particularly to be that, in the first, the umbra, instead of being freed from the gases and vapors, is partly or wholly choked with them; while, besides, the chromosphere covers it. The forces which open the photosphere in high latitudes, it would seem, have not sufficient energy to repel or dissolve the chromospheric gases; or, if they have, it is in a very feeble degree, but, even then, the phenomenon is generally of short duration.

Though I had no means of making accurate measurements of the position of the spots seen in high latitudes, the error of my estimation cannot be very great. In any case a few degrees would certainly cover it, and it remains a fact that I have observed spots at least within 10° of the north pole of the sun. The importance of this observation will appear when it is stated that very few spots have been observed outside of the zones lying 40° on either side of the equator. I know of but two instances on record in which spots have been observed beyond this limit. La Hire observed a spot 70° from the equator, and more recently, in the month of June, 1846, M. Peters observed at Naples a spot 50° from the equator.

It is further to be remarked that, according to the conclusions of the English observers, the solar spots attain higher latitudes during the years of the maximum number of spots, and recede more and more towards the equator as the minimum is approaching; and it is to be noted that the present year is precisely, or at least very nearly, a minimum year. It is doubtless owing to the unusual thinness of the chromosphere during this period that spots have been observed in so high latitudes this year. It is true that the spots were small, but, nevertheless, they were genuine spots, with all the characteristics of larger spots.

It is difficult for one who has seen the phenomena which I have described, to come to any other conclusion than this: that the veiled spots are breaks or true openings in the photosphere, seen through the imperfectly transparent gases composing the chromosphere, openings themselves partly or wholly filled by the vapors ejected by the forces from the interior of the photosphere. If this hypothesis should prove to be the expression of a fact, then we should expect to find that the photosphere is perforated by thousands of crevasses either partly or entirely filled with the vapors and gases from the interior, which cannot be ejected entirely outside for want of sufficient energy, save for a comparatively very small number situated in the equatorial zones, where this energy appears maximum, and is able to repel and dissolve the gases from the interior.

Before the observations of this year, I had arrived at precisely the same conclusions in regard to the openings of the photosphere in all latitudes, and to the existence of invisible spots concealed by the chromosphere. These conclusions were derived from my observations with the spectroscope, made at Harvard College Observatory during a period of thirty-five months. A discussion of these observations is reserved for a future communication.

Though one can hardly form a settled opinion with regard to the cause of the general depression of the chromosphere, on account of the imperfect data, it seems natural, however, to suppose that the phenomenon is connected in some way with the minimum period of sun spots. Judging by the great number of veiled spots observed, and by the myriads of pores seen between the granulations, it would seem that both the chromosphere and photosphere have been much thinner than usual during the present year.

If there are breaks in the photosphere at many points of the surface of the sun, it becomes easy to account for the unusual thinness of the chromosphere this year, because, as observed by myself and others, at certain phases of the spots, the chromospheric gases, rushing with impetuosity into the umbra, go down under the photosphere like gigantic waterfalls, diminishing consequently the thickness of the chromosphere. That this takes place I shall give ample proof in another communication.

It seems evident that the chromosphere near a spot is kept off from falling into the opening by a force from the interior. As soon as this force decreases in energy, immediately the chromosphere tends to cover it, and even to precipitate itself through the opening when this force becomes extinct. The observations show this plainly.

When a spot is decreasing, it is quite common to observe that the umbra and penumbra appear as if they were seen through a heavy fall of snow, their surfaces being covered by numerous bright flocculent granulations surrounded by a kind of bluish fog. In a few instants of very rare definition, I have been surprised to see faint traces of this flocculent appearance upon almost all the spots; indeed it would seem that the spots are rarely free from some faint traces of the chromospheric gases. Probably the bright flocculent objects observed upon the umbra and penumbra of spots, are the granulations of the chromosphere dissolved to a greater or less degree by the forces emanating from the spots.

Perhaps it may not be idle to remark that, during the period mentioned, I have almost every day observed small groups of faculæ in the polar regions, especially near the north pole of the sun; while, for the most part, they have been entirely absent from the equatorial regions, where they are commonly found.

To conclude, my observations show: —

1°. That during this year, and especially during the interval from June 10 to August 18, and to a less degree to September 14, the chromosphere has been notably thinner than usual upon the entire surface of the sun.

2°. That the granulations have been smaller and less numerous.

3°. That the light-gray colored background seen between the granules has been more conspicuous and has occupied more space than usual.

4°. That there are spots, which I have named "veiled spots," which are seen through the chromosphere which is spread over them like a veil.

5°. That these veiled spots are true openings of the photosphere, like those of the ordinary spots.

6°. That during this period these spots have been larger, darker, and more numerous than I have before seen them.

7°. That the veiled spots are scattered throughout all latitudes, though more complicated in the regions where the ordinary spots make their appearance.

8°. That I have observed spots at least within 10° of the north pole of the sun.

9°. That the flocculent objects sometimes seen projected upon the umbra and penumbra of spots are the remaining portion of the granulations composing the chromosphere, more or less dissolved by the forces emanating from the interior of the photosphere.

CAMBRIDGE, October 1, 1875.